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Understanding Research Collaborations using Social Network Analysis: A Case Study of Indian Institutes of Technology

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Abstract— Co-authorship is of the most pervasive forms of research collaboration and the co-authorship data can be obtained with some amount of efforts as there are a number of online resources which store publications data in an organized manner. These resources include digital libraries like DBLP, Microsoft Academic Search, etc. In addition to these resources some institutional website also provide publications data of people working with them. One can use any of these resources to obtain this co-authorship information from joint publications. These co-authorship relationships form the basis of co-authorship based academic social networks. In this paper we obtained publications data of Computer Science Engineering Departments of four top ranked Indian Institutes of Technology for a ten year period 2005-2014 in order to understand various micro (individual) and meso (departmental) level research indicators using social network analysis metrics. The results that we obtained were promising and provided interesting findings about the research credentials of these institutes.

Keywords— Co-authorship networks, centrality measures, research collaborations, social networks, IITs.

I. INTRODUCTION

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Research collaboration can be defined as "*the working together of researchers to achieve the common goal of producing new scientific knowledge*" [1]. Scientists and researchers world over collaborate with their peers within and outside their organization to produce joint research. These collaborations have been studied amply in different settings and different domains previously. Before the advent of Internet it was quite difficult to keep track of these collaborations in a convenient way but the advances in Information and Communication Technology has made such collaborations more easy and frequent on one hand and much more manageable and accessible on the other [2]. Online literature management services like Springer Link, etc. or digital libraries like DBLP, etc. index a large number of publications. Metadata about these publications (co-authored) provide structured information about co-authorship relationships in addition to other publication attributes.

Research is one of the main focuses of higher academic institutions like universities, technical institutions and research laboratories. Researchers publish their work for a number of reasons [3, 4] including career progression, personal reputation and sense of achievement, contribution to the existing body of knowledge, getting visible and eligible for quality collaborators, finding research funding, etc. The interdisciplinary nature of the modern day research has served as a catalyst for joint research and thus joint publications. These co-authored publications form the basis of co-authorship based academic networks as people who appear as co-authors of a publication are professionally related to each other in some way or the other [5]. Understanding these networks from social network analysis (SNA) point of view provide information about co-authorship patterns, strength of co-authorship, important people in these networks, etc.

Developing countries like India tried to follow the West in a number of ways, technical education being one of them. In this context, among other measures, Indian Institutes of Technology (IITs) were established in early the early days of independent India to provide quality manpower for providing the much needed impetus to economic and social development. These institutes were mandated to lead in technology development by providing world class technocrats which in no ways could be possible without creation of new knowledge by means of research and development. Keeping the status of IITs in the Indian technical education in view we choose to study the co-authorship trends in four top ranked IITs viz. IIT Kanpur, IIT Delhi, IIT Kharagpur and IIT Madras as per Nelisen Best Colleges Survey 2014[1]. Some of objectives of this study are:

- Visualization and analysis of the co-authorship networks emerging out of joint publications both within a particular department as well as outside the department;
- Understanding the pattern, frequency and strength of joint publications produced by people affiliated with each of these IITs during the period under investigation;

[1] INDIA TODAY Nelisen Best Colleges Survey 2014:http://indiatoday.intoday.in/bestcolleges/2014/ranks.jsp?ST=Engineering&LMT=2&Y=2014

- Identification of influential people and groups in each of these networks and role they play in flow of knowledge, exist as bridge between desperate people and groups, etc.;
- Analysis of the network behaviour of these co-authorship networks and their comparison with established network structures like smallworld, scale-free, etc.

II. RELATED WORK

SNA makes visible these otherwise invisible patterns of interaction, to identify important groups in order to facilitate effective collaboration [6]. SNA has been employed previously to study co-authorship networks formed among conference participants [7, 8, 9, 10], journal publications over a period of time [9, 11, 12, 13], specific domains like Information Science, Database, Physics, etc. [9, 14, 15] and by people working with specific institutions [16]. The aim of these studies was to investigate the structure and important actors in these networks based on social network analysis metrics. A range of studies from those studying co-authorship based research collaborations at local, national and international level [2] to those focusing on the impact of research collaborations in innovation and development of new industries [17] have used SNA and SNA metrics to provide insight into these networks.

Domain specific studies include [15] which studies the collaboration pattern, number of authors, trend in joint publications, rise of literature, etc. in Chinese humanities and social science. Another study [14] concentrates on number of factors from the point of view of SNA in the field of biological medicine, physics, and computer science. DBLP is a major Computer Science bibliography with 28,58,971 publications as on January 20, 20152. Around 55 percent of these publications appear in conferences. Taking the availability of vast amount of publications data into consideration [7] study the co-authorship networks in various viz. KDD, VLDB, ICML and WWW listed by DBLP. In the Indian context [10] study the collaboration pattern in seven consecutive issues of International Conference on Contemporary Computing one of the major destination for quality publications in the subcontinent. In addition to studying the co-authorship networks among the individual participants [10] analyzed institutional collaboration on the basis of affiliation of individual authors.

Collaboration patterns among the papers published in some of the leading journals have also been addressed on some of the studies, e.g. Scientometrics journal [11], Educational Technology & Society journal [13], Journal of Research in Medicine [12]. In addition to collaboration patterns these studies also identified authorship trends, average number of authors, number of groups in which the entire network is divided, etc. Relevance of social network analysis metrics in the academic social networks has been discussed in detail in [13].

Some of these studies [10, 12, 13] have also identified individual actors in the underlying network and thus can be called as star authors. As a matter of fact institutional collaborations have not been the focus of any of the related studies that we have reviewed to the best of knowledge no such study exists in the public domain till date.

III. DATA COLLECTION

Publications data available on the websites of the four IITs was extracted using a java based data extraction tool which is under development and needs further fine tuning before it can be applied for publication (metadata) extraction from heterogeneous sources. The working and explanation of the tool is beyond the scope of this paper. Using the HTML structure attributes of each publication were extracted and saved as MS-Excel file. Since each of these IITs presented their publications data in different format the data extraction tool was modified to suit to the changing requirements. After extraction and bring the data in common format duplicate records were searched automatically and removed. The publications data was disambiguated and different name variations of same author were normalized by using combination a token based and a character based string similarity measure. The name disambiguation mechanism employed here is modified version of [18].

The statistics of data collected and some of the key indicators extracted from the obtained publications data are presented in Table-I. Cumulatively the concerned department of these IITs produced 1881 publications during the ten year period which included 1818 joint publications. These joint publications produced 8187 co-authorship records.

TABLE I STATISTICS OF THE DATA FOR THE PERIOD OF STUDY

IIT	**Delhi**	**Kanpur**	**Kharagpur**	**Madras**
Total Publications	371	311	411	788
Single Author Publications	17	22	9	15
Joint Publications	354	289	402	773
Percentage of Joint Publications	95.42	92.93	97.81	98.10
Co-authorship Relationships	2093	1004	2108	2982

IV. EXPERIMENTS AND RESULTS

We extracted co-authorship based academic social networks of Computer Science Engineering Departments of four IIT under consideration for a ten year period from 2005-2014. The extracted social network graphs are shown in Fig.1. The strength of collaboration in all the graphs presented in this work is depicted using different coloured edges. Red edges indicate strong ties, green indicate moderately strong ties, blue indicate moderately weak ties, and cyan indicate

[2] http://www.informatik.uni-trier.de/~ley/statistics/recordsindblp.html

weak ties. The width of an edge in these also shows the strength of collaboration between any two vertices in the graph. From these graphs various social network analysis metrics have been used to study the collaboration pattern, the number of different groups in each of these networks, total number of authors associated with these publications, etc.

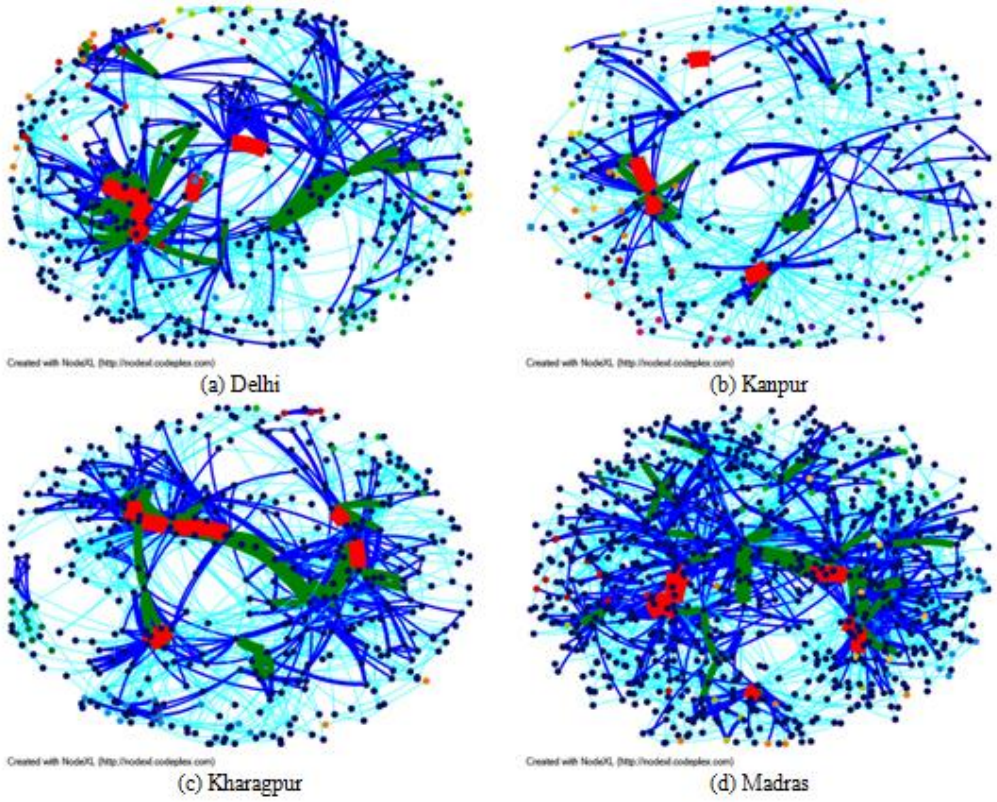

Fig.1: Co-authorship graphs

Table-II lists the values of some important network metrics obtained for these graphs. These values have been obtained from NodeXL[3] Graph Metrics Calculation facility provided in the NodeXL Microsoft Excel Template.

From the values of 'Vertices' for each of the four IITs it can be observed that the co-authorship network of IIT Madras has the highest number of authors associated with joint publications produced during the period under investigation, IIT Delhi follows next. The value of 'Total Edges' in Table-II specifies the total number of co-authorship relationships recorded, IIT Madras again leads the other three IITs in this case with 2982 total co-authorship relations for 773 joint publications. This means that there are 3.86 co-authors for each of the joint publications produced by IIT Madras. This value is 5.25 for Kharagpur, 3.48 for Kanpur and 5.92 for Delhi. The average number of co-authors per publication in each of these cases were either above or almost equal to the average number of co-authors in the disciplines of Biology and Physics as observed by [14] to be 3.75 and 2.53 respectively. These values were quite higher to those in case of co-authorship networks formed among authors of Educational Technology & Society journal (1.43) studied in [13] but in the range of those obtained for Journal of Research in Medicine (5.21) [12]. This implies that same authors work on joint publications more often in IIT Delhi and Khargapur but less in case of IIT Madras and Kanpur.

One more interesting feature of these graphs is the number of potential relationships (co-author) that were actually converted into reality. This can be obtained by using the value of 'Graph Density'. In percentage terms IIT Delhi converted only 1.12% of the total possible relationships into actual relationships. This is 1.05% for Kanpur, 1.45% for Kharagpur and 0.53% for Madras. This percentage is quite high in case of domain specific conference, journals, etc. as studied in [12]. The idea about recurring co-authorships can be obtained from the value of 'Edges with Duplicates'. In IIT Delhi the percentage of duplicate edges is 53.08%, it is 38.75%, 61.20% and 51.84% for IIT Kanpur, Khargapur and Madras respectively. Thus in case of IIT Delhi the percentage of same authors writing repeatedly with each other is higher as compared to the other three.

It is interesting to note that despite being comparatively large networks with more than 400 vertices the networks of IIT Delhi, Kharagpur and Madras are divided in 8, 6 and 8 subgroups 'Connected Components' respectively. So in case of these three IITs it can be observed that majority of the authors produce joint publications and are related to each other by way of being co-authors. Each of the four networks have one such connected component, called as giant component, that has more number of vertices and edges as compared to other connected components. In IIT Delhi the giant component has 83.94% of the total vertices and 88.63% total edges, in IIT Kanpur it is 79.52% of total vertices and 84.46% of total edges, in IIT Kharagpur it is 92.27% of the total vertices and 94.55% of total edges, in Madras it is 91.90% of total vertices and 92.99% of the total edges. This means a large number of authors form a cohesive collaborative group that is collaborating more often with each other directly or indirectly.

[3] NodeXL: http://nodexl.codeplex.com/

TABLE III VALUES OF VARIOUS CO-AUTHORSHIP GRAPH METRICS

IIT	**Delhi**	**Kanpur**	**Kharagpur**	**Madras**
Joint Publications	354	289	402	773
Vertices	492	376	414	864
Unique Edges	982	615	818	1436
Edges with Duplicates	1111	389	1290	1546
Total Edges	2093	1004	2108	2982
Average Geodesic Distance	4.495213	4.687331	3.620508	4.892994
Maximum Geodesic Distance	10	12	7	12
Graph Density	0.011169	0.010511	0.0144306	0.005234
Maximum Degree	52	68	58	121
Average Degree	5.484	3.941	5.908	4.516
Maximum Betweenness Centrality	44287.075	21441.269	13577.080	206147.880
Average Betweenness Centrality	610.415	442.803	463.222	1422.853
Maximum Closeness Centrality	0.333	1.000	1.000	0.250
Average Closeness Centrality	0.013	0.044	0.015	0.006
Maximum Eigenvector Centrality	0.048	0.073	0.032	0.045
Average Eigenvector Centrality	0.002	0.003	0.002	0.001
Connected Components	8	14	6	8
Maximum Vertices in a Connected Component	413	299	382	794
Maximum Edges in a Connected Component	1855	848	1993	2773
Average Clustering Coefficient	0.820	0.760	0.799	0.767
Modularity	0.317845	0.365475	0.281603	0.287678

In co-authorship networks 'Average Clustering Coefficient' specifies the chances of an two indirect co-authorship relations being converted into direct co-authorship relations in the future. This it is a measure of quantifying the evolution of co-authorship networks. From the value of 'Average Clustering Coefficient' it emerges that around 82.0% indirect co-authors of IIT Delhi may produce joint research in future. This value is 76.0%, 79.9% and 76.7% for IIT Kanpur, Kharagpur and Madras respectively. From this it can be deduced that all four IITs are evolving as a close knit community there by making flow of knowledge and ideas in these networks easy and convenient.

These networks (Fig.1) exhibit the same type of behavior as majority of the social networks studied previously. These networks exhibit '*smallworld*' behaviour as the average distance between any two nodes (Average Geodesic Distance) in the network is less than 6 in all the four networks. The lesser the distance between any two nodes in the network the easier is the flow of information in the network. In co-authorship networks it implies that no two authors in the network are beyond the reach of one another. Of all the four IITs, Kharagpur has the lowest value of 'Average Geodesic Distance' which means that people who appear as authors in the joint publications produced by IIT Kharagpur have close relationship (co-authorship) with each other and the flow of knowledge and ideas is much more easier.

It was observed that number of joint publications has increased a lot over a period of time. Out of a total of 371 publications during the specified period the concerned department of IIT Delhi produced 95.42% joint publications. The percentage of joint publications produced during the period was 92.93%, 97.81% and 98.10% for IIT Kanpur, Kharagpur and Madras respectively. Such high percentage of joint publications can be attributed to the domain of the publications under consideration. It has been observed that in technical disciplines it is not possible for a single person to produce good number of quality publications. This is because the modern nature of scientific research requires understanding of diverse subject disciplines.

Star Authors

As per [19] centrality is a sociometric concept of the star i.e. the most popular person or the person at the centre of attention. Various centrality measures like degree centrality, betweenness centrality, closeness centrality and eigenvector centrality are some of the micro-level social network analysis metrics that play an important role in identifying important individuals in social networks. Use these micro-level metrics we can identify who acts as hubs/leaders, who commands the highest number of connections, who acts as an important link in the flow of information in the network i.e. gatekeeper in the network, how enjoys strong connections etc. Identification of vital actors (authors in case of academic social networks) using such metrics help in discovering possibilities and challenges that describe the behaviour of individuals in a social setup [20]. Such identification gives an idea about the relative importance of the people working for an institution (actors in the target academic social network) and help predicting the consequences of removal of any of these actors from the network, which may be because of various reasons like their retirement, jobs switching,

deputation to other organizations, death, etc. Identification of important individuals (researchers) has been done in almost all the studies which use SNA to study co-authorship networks [12]. Table-III presents the identified centrality values (degree, betweenness, closeness and eigenvector centrality) of the top ten authors of each of the four IITs.

TABLE IIIII TOP 10 AUTHORS IN EACH OF THESE SOCIAL NETWORKS BASED ON CENTRALITY VALUES.

IIT	**Degree Centrality**		**Betweenness Centrality**		**Closeness Centrality**		**Eigenvector**	
	Author	**Value**	**Author**	**Value**	**Author**	**Value**	**Author**	**Valu**
Delhi	Aaditshewar Seth	52	Samuriti R.	44287.0	Saroj Kaushik	0.12	Aaditshewar	0.04
	Kolin Paul	46	Vinay Joseph	25240.9	Arzad Alam	0.10	Vinay Joseph	0.02
	Vinay Joseph	45	Amitabha Bagchi	22487.2	Mausam	0.04	Rajat Bhatia	0.01
	Samuriti R.	43	M. Balakrishnan	18885.9	Samuriti R.	0.00	Amitabha	0.01
	Amitabha Bagchi	43	Kolin Paul	14301.7	Vinay Joseph	0.00	Samuriti R.	0.01
	M. Balakrishnan	31	Naveen Garg	12778.1	Preeti Ranjan	0.00	Huzur Saran	0.00
	Naveen Garg	30	Aaditshewar Seth	12455.2	Aaditshewar	0.00	Preeti Ranjan	0.00
	Prem Kumar	29	Preeti Ranjan	8617.65	Amitabha	0.00	Amitabh	0.00
	Mausam	21	Prem Kumar	7022.91	Huzur Saran	0.00	M.	0.00
	Subhashis	21	Shyam K. Gupta	6419.66	Anshul Kumar	0.00	Maya Ramnath	0.00
Kanpur	Amitabha	68	Amitabha	21441.2	Ajai Jain	0.33	Amitabha	0.07
	Ratan K. Ghosh	37	Ratan K. Ghosh	14761.5	Sanjeev Saxena	0.25	Pabitra Mitra	0.01
	Phalguni Gupta	27	Pankaj Jalote	11485.0	Akshay Mittal	0.25	Ratan K. Ghosh	0.01
	Sanjeev K.	23	Somenath Biswas	9217.71	Arnab	0.04	Harish Karnick	0.01
	Pankaj Jalote	22	Sanjeev K.	8539.66	Amitabha	0.00	Pankaj Jalote	0.00
	Harish Karnick	21	Phalguni Gupta	6536.35	Ratan K. Ghosh	0.00	Dheeraj Sanghi	0.00
	Arnab	19	Dheeraj Sanghi	5024.19	Pankaj Jalote	0.00	Sanjeev K.	0.00
	Dheeraj Sanghi	18	Harish Karnick	3000.48	Sanjeev K.	0.00	Saurabh	0.00
	T. V. Prabhakar	12	T. V. Prabhakar	2776.50	Dheeraj Sanghi	0.00	Phalguni Gupta	0.00
	Somenath Biswas	11	Surender	2343.00	Somenath	0.00	Somenath	0.00
Kharagpur	Partha P.	58	Rajib Mall	13577.0	Rajesh Kumar	0.00	Pallab	0.03
	Pallab Dasgupta	54	Arun Kumar	12255.5	Arun Kumar	0.00	Partha P.	0.03
	Rajib Mall	47	Partha P.	11733.1	Jayanta	0.00	Ansuman	0.01
	Niloy Ganguly	47	Rajesh Kumar	10616.0	Sujoy Ghose	0.00	Subhankar	0.01
	Jayanta	34	Niloy Ganguly	9527.28	Partha P.	0.00	Arun Kumar	0.01
	Rajesh Kumar	31	Indranil Sen	9047.44	Pallab Dasgupta	0.00	Jayanta	0.01
	P. K. Bhowmick	30	Pallab Dasgupta	8890.78	Niloy Ganguly	0.00	Rajesh Kumar	0.01
	Debdeep	26	P. K. Bhowmick	6717.89	Indranil Sen	0.00	Niloy Ganguly	0.00
	Indranil Sen	23	Jayanta	6574.84	P. K.	0.00	P. K.	0.00
	Anupam Basu	22	Sujoy Ghose	6560.15	Rajib Mall	0.00	S. K.	0.00
Madras	Balaram	121	Balaram	206147.	Balaram	0.00	Balaram	0.04
	V. Kamakoti	90	V. Kamakoti	123753.	V. Kamakoti	0.00	V. Kamakoti	0.02
	C. Pandu Rangan	75	Hema A. Murthy	78003.3	Sukhendu Das	0.00	Sukhendu Das	0.01
	C. Siva Ram	48	Sukhendu Das	60070.9	Hema A.	0.00	V. S.	0.00
	Madhu Mutyam	47	C. Pandu Rangan	56004.1	Suatnu	0.00	Suatnu	0.00
	Hema A. Murthy	44	Suatnu	40513.6	Deepak	0.00	Hema A.	0.00
	Krishna	40	C. Siva Ram	34811.5	Madhu Mutyam	0.00	Madhu Mutyam	0.00
	D. Janakiram	32	Madhu Mutyam	33166.1	N. S.	0.00	Kumar P.	0.00
	Deepak Khemani	31	N. S.	32170.1	D. Janakiram	0.00	Arun Kumar	0.00
	N. S.	29	Deepak Khemani	31194.3	Shankar	0.00	Deepak	0.00

The IITs command a lot of authority in the Indian technical education scenario and there is a large number of audience even if they matter to just one percent of the Indian population (1.2 million people). Thus identification of star performers in IITs can be considered substantial contribution to the scientometric field. In addition to serving as personal satisfiers and relative ranking the micro-level metrics help in the identification of star actors in these networks which may

help us find potential people who can be approached for collaborative research, research guidance, consultancy work, expert lectures, chairing technical sessions, reviewing journal and conference papers, etc.

Aditeshwar Seth has highest degree (52) and highest eigenvector centrality (0.048) in IIT Delhi. Samurti R. Sarangi has highest betweenness centrality (44287.075) whereas Saroj Kaushik has highest closeness centrality (0.125). Higher eigenvector centrality means connections with other high ranked actors (authors). Higher value of eigenvector centrality for Aditeshwar Seth means that in addition to having highest number of connections (degree) he has connections with other nodes which in turn also have high degree. These include Vinay J. Ribero (45), Anirban Mahanti (24), Sandeep Sen (20), etc. Thus in the co-authorship network of IIT Delhi (Fig.1(a)), Aditeshwar Seth controls the flow of information by acting as gatekeeper and his removal from this network may make difficult the flow of information. In addition he also holds a central position by having connections with other high profile nodes (authors), thus he enjoys the position where he is the first one to receive new ideas that emerge in the network.

In IIT-Kanpur Amitabha Mukerjee has highest degree (68), highest betweenness centrality (21441.269) and highest eigenvector centrality (0.073). This implies that the co-authorship network of IIT Kanpur exhibits somewhat same behavior as IIT Delhi as like Aditeshwar Seth of IIT Delhi Amitabha Mukerjee of IIT Kanpur is the star actor with highest number of connections, controls the flow of information by sitting at the gateway of the network and enjoys connections of other high profile actors in this network co-authorship network of IIT Kanpur as he sits as a gatekeeper in this network and also enjoys the collaborations of other high profile nodes in the network (Fig.1(b)).

In case of IIT-Madras which stands atop the other three counterparts with highest number of publications Balaram Ravindran has highest degree (121), highest betweenness centrality (206147.880) and highest eigenvector centrality (0.045). Thus Balaram Ravindran not only produced joint publications with maximum number of other authors but also kept in mind who to co-author with. This has helped him in scoring high in terms of eigenvector centrality. He also acts as gatekeeper in this network and thus becomes instrumental in reception of new ideas and concepts that emerge in the process of knowledge creation in the co-authorship network of IIT Madras.

The centrality based distribution of actors in co-authorship network of IIT-Kharagapur (Figure-1(c)) is different from that of IIT Delhi, Kanpur and Madras. Three different authors Partha P. Chakrabarti, Rajib Mall and Pallab Dasgupta figure at top in terms of highest degree (58), highest betweenness centrality (13577.080) and highest eigenvector centrality (0.032) respectively. This implies that Partha P. Chakarbarti may have highest number of connections but the quality of connections of Pallab Dasgupta is better as compared to those of Partha P. Chakarbarti. Thus just having higher number of connections may not rate you better in terms of eigenvector centrality the quality of those connections also matters a lot. The closeness centrality of all the top ten authors is equal.

V. CONCLUSIONS

We extracted co-authorship based academic social networks of four top ranked IITs in India. The choice of these institutes was quite natural as institutes of higher education in India they enjoyed a lot of benefits which include liberal funding by the government, world class faculty and infrastructure and are ranked highest in terms of choice for student aspirants. They are always at the fore front of technical education in Indian and number of other institutions takes them as their role model. Through this study we extracted publications data from the websites of these IITs and analysed co-authorship based academic social networks of their Computer Science Engineering Departments. These publications included 1818 joint publications and 8187 co-authorship records.

In addition to reporting the research productivity of these institutes we analysed the collaboration patterns at meso-level analysis and star authors at micro-level. We identified important actor and listed them in order in terms of four centrality measures. Identification of these individuals in top ranked IITs matter for just one percent of the Indian population it is of interest for 1.2 million people, which is comparatively a large number. The statistics presented in Table-II show that these networks are divided into a number of sub-groups (connected components) but interestingly each of the four networks have one such giant component which comprises of more than ninety percent of total vertices and edges. Thus we can say that majority of the people working with these institutes carry out joint research and are actively engaged in collaborative work

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